

Neutral pion production in Au+Au collisions at RHIC



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Jet Quenching

Hadron production sensitive to:

- Initial state interactions
- Hot medium (suppression)
- Cronin effect (enhancement)

Central Au+Au: hadrons suppressed

Comparing Au+Au to p+p:

Nuclear Modification Factor

$$R_{AA}^h(p_T, \eta) = \frac{1}{\langle N_{\text{bin}} \rangle} \frac{d^2\sigma_{AA \rightarrow h}/dp_T d\eta}{d^2\sigma_{pp \rightarrow h}/dp_T d\eta}$$

- Strong centrality dependence
- Photons: no suppression

- No suppression in d+Au

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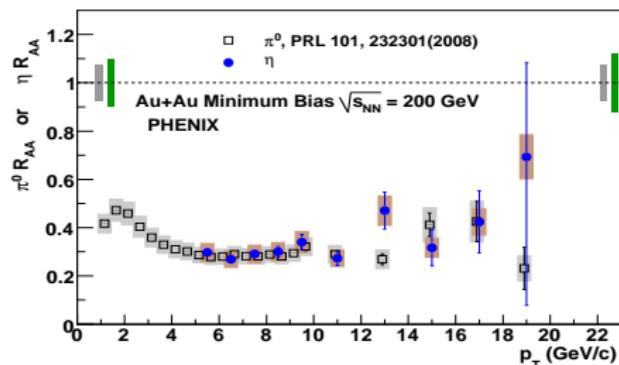
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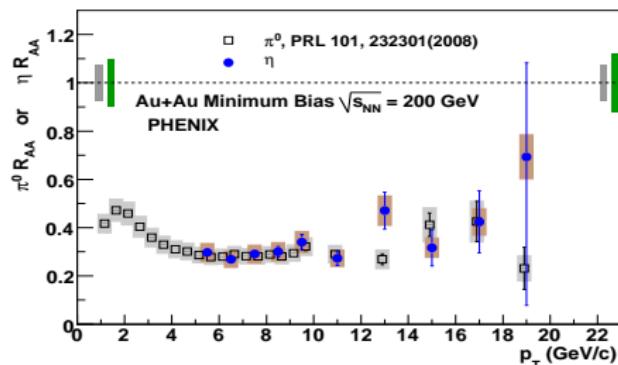
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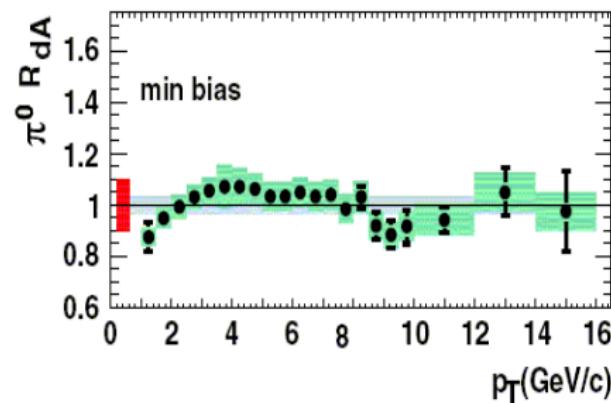


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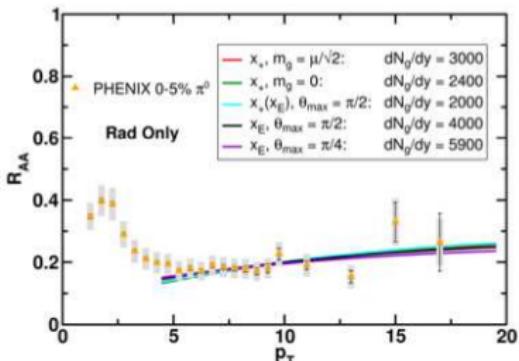
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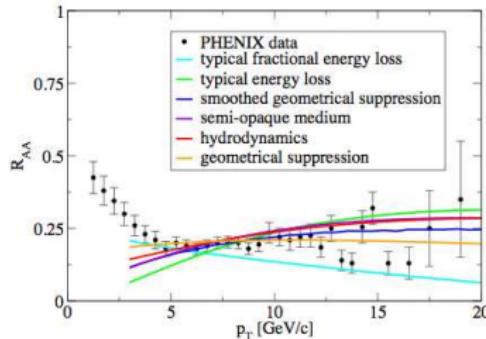


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Theoretical motivation



Horowitz, Cole, PRC81, 024909



Different model classes on the market

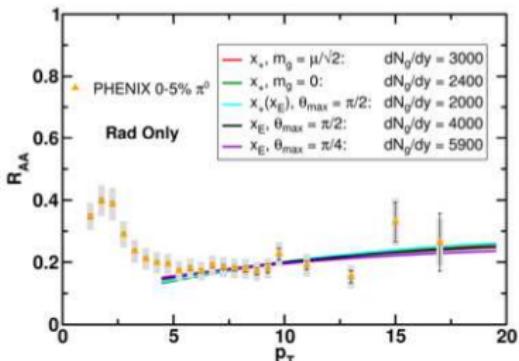
GLV Opacity expansion (Gyulassy, Lévai, Vitev)

BDMPS-Z-ASW Multiple soft scattering (Wiedemann, NPB588)

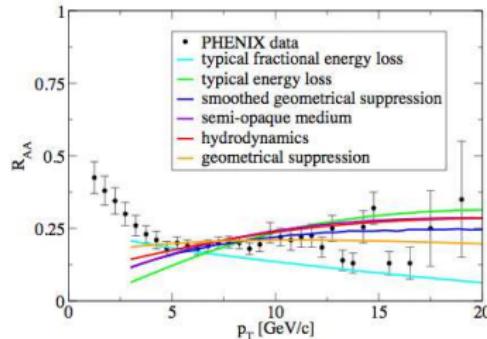
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AMY Thermal field theory (Arnold, Moore, Yaffe)

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R_{AA} not restrictive enough on models

Additional input required to discriminate b/w different mechanisms

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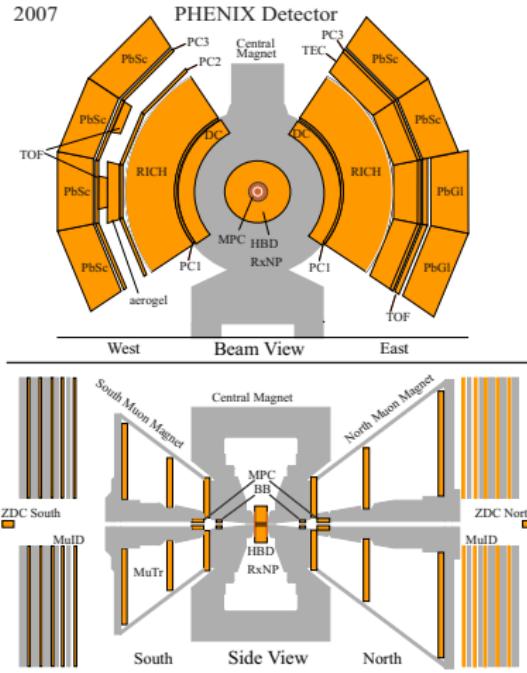
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The PHENIX experiment (2007)

2007



Reconstruction of $\pi^0 \rightarrow \gamma\gamma$

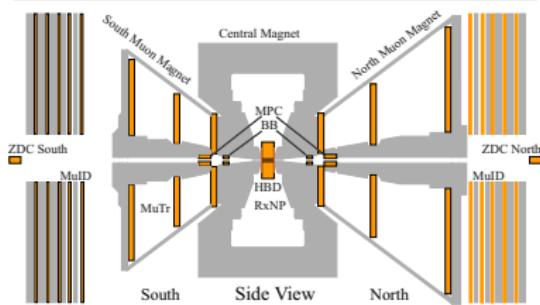
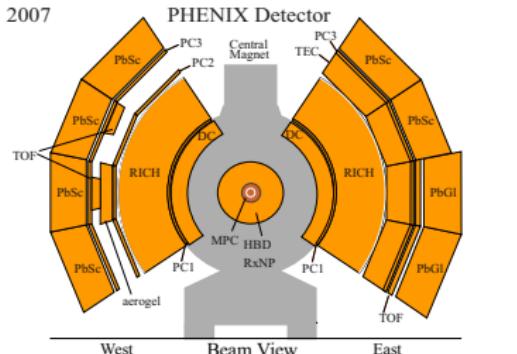
- Calorimeter: **PbSc** and **PbGi**
 $|\eta| \leq 0.35$
- photons detected
- cluster merging negligible
below $p_T < 12 \text{ GeV}$

Reaction plane determination

- RxNP** (Plastic Scintillator)
 $1.5 \leq |\eta| \leq 2.8$
- MPC** (PbWO₄ Crystals)
 $3.1 \leq |\eta| \leq 3.7$
- Improved v_2 determination

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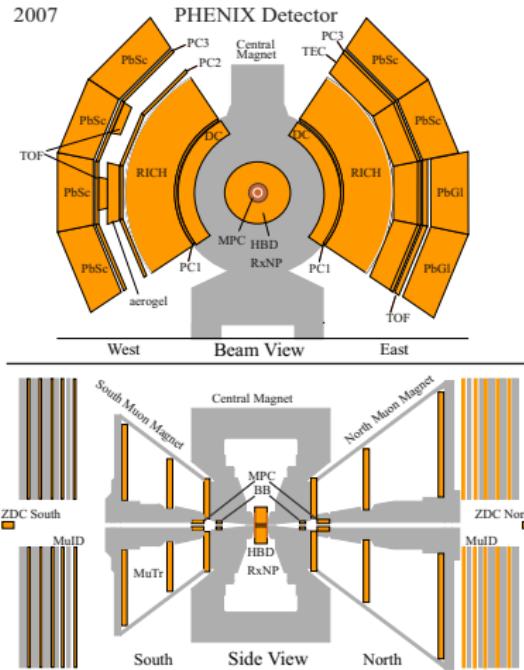
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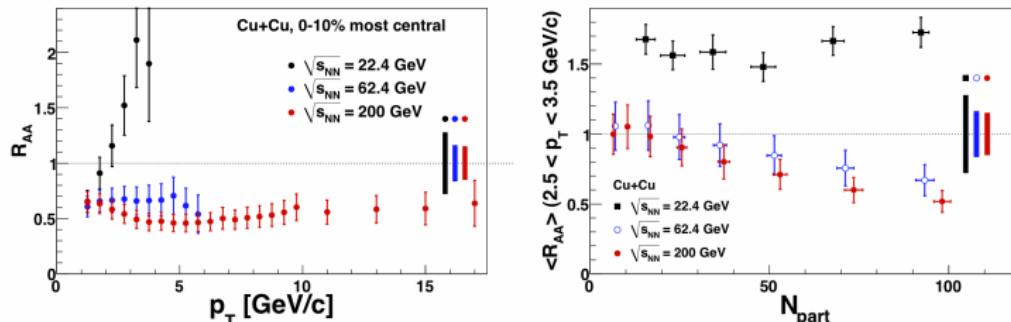
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Evolution of suppression w.r.t. system size, energy

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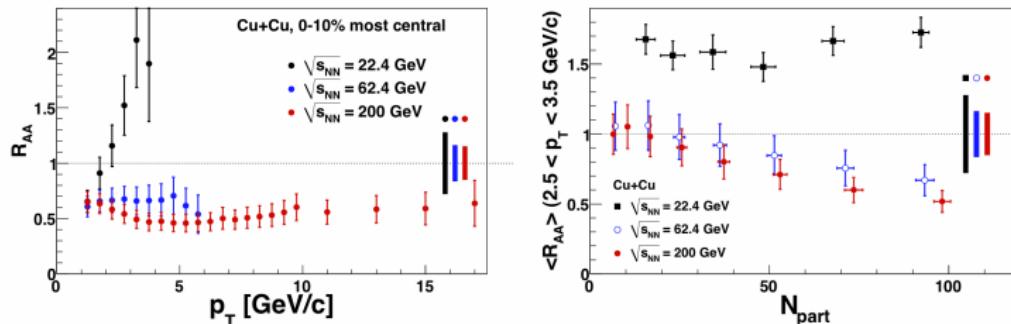


Energy dependence in Cu+Cu (smaller system)

- Suppression in central 62.4 GeV and 200 GeV
- No suppression in peripheral
- Enhancement at 22.4 GeV (\sim constant)

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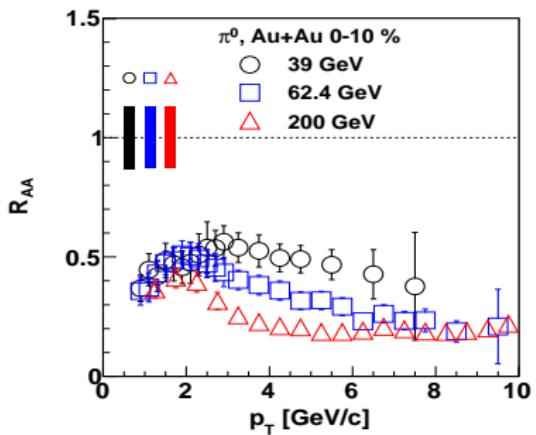


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Au+Au central R_{AA} from 32 to 200 GeV (2010 data)

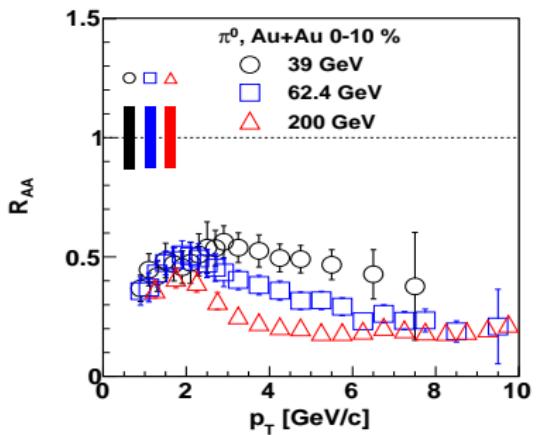
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- Strong suppression in central collisions even at 39 GeV
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- Central data comparable with GLV model
Solid curves represent 30% higher initial-state parton mean free paths corresponding to a larger Cronin effect)

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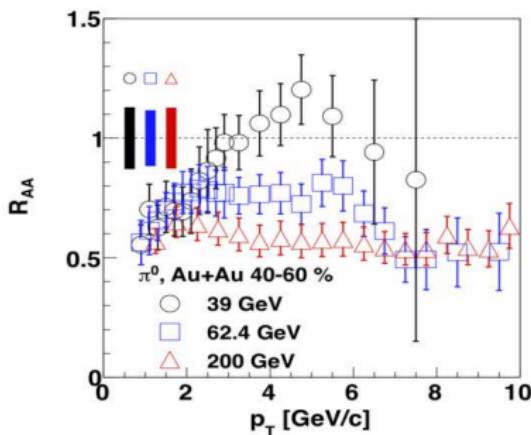
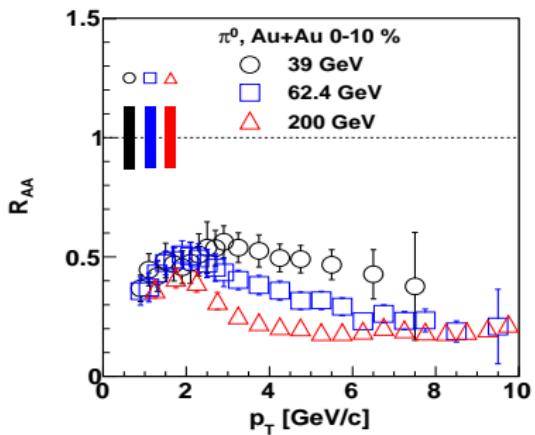
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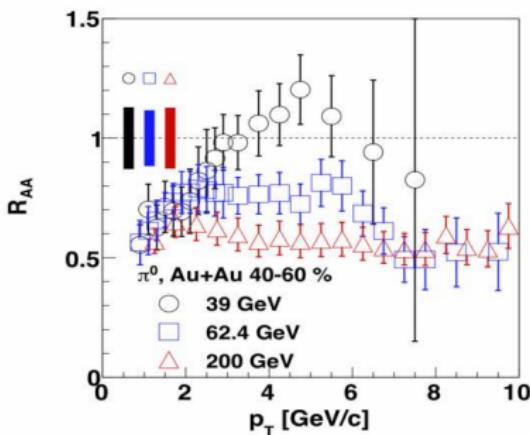
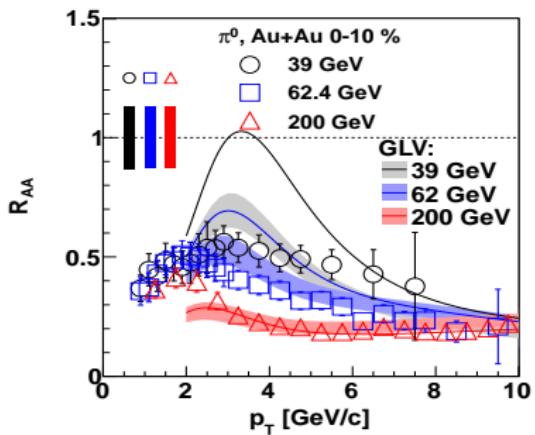
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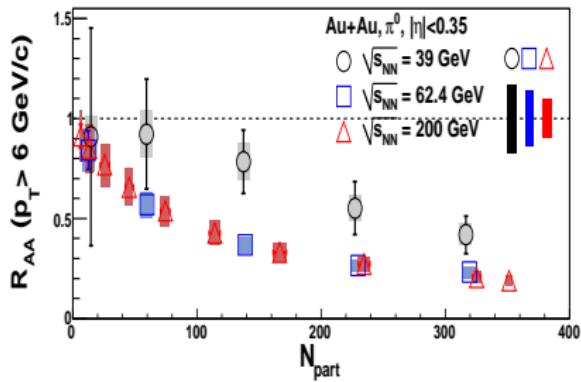
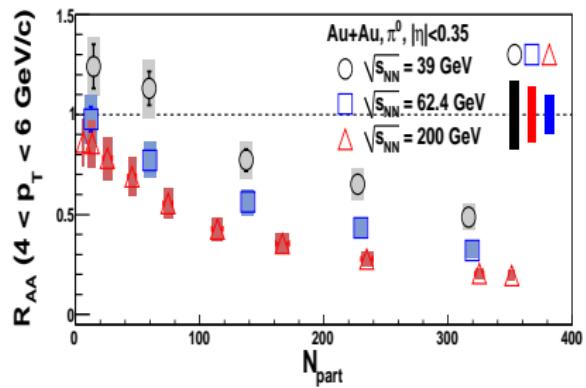
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Integrated R_{AA}

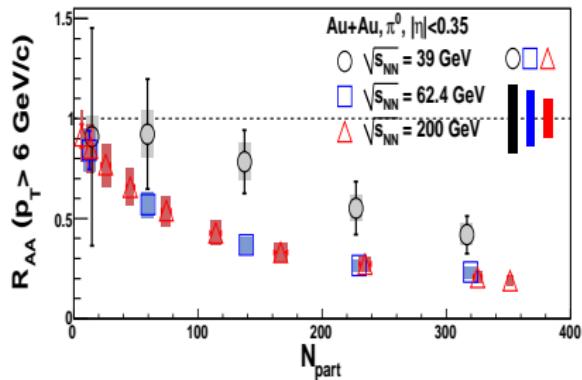
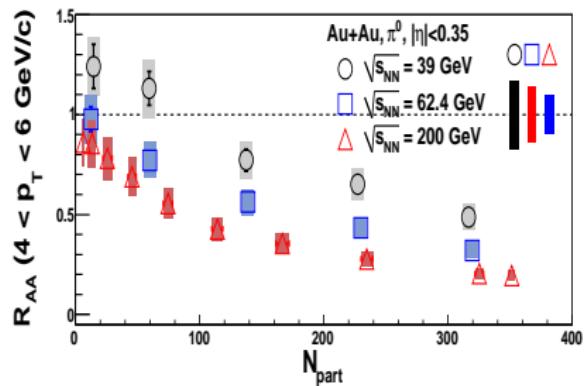
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- 62.4 and 200 GeV data shows strong suppression even in more peripheral collisions
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- No significant difference between 62.4 and 200 GeV data points if $p_T > 6$ GeV/c

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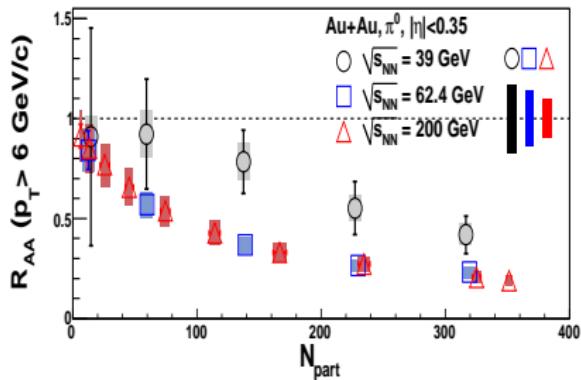
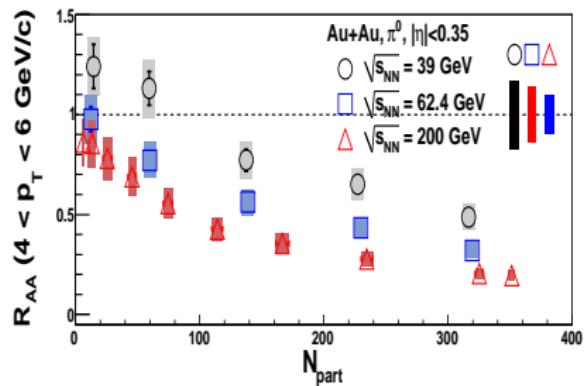
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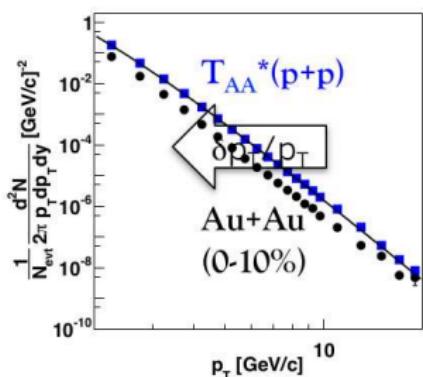
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Fractional energy loss

Horizontal shift of Au+Au spectrum from properly scaled p+p



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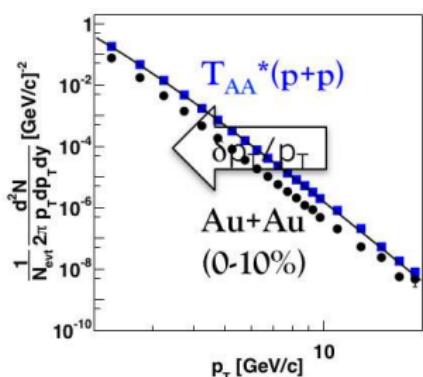
$$S(p_T) = \delta p_T / p_T$$

- Largest energy loss in 200 GeV
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 $S(p_T) < 0$ corresponds to $R_{AA} > 1$
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Note: Cronin-effect is \sqrt{s} -dependent and it is negligible at $\sqrt{s_{NN}} = 200$ GeV (see d+Au)

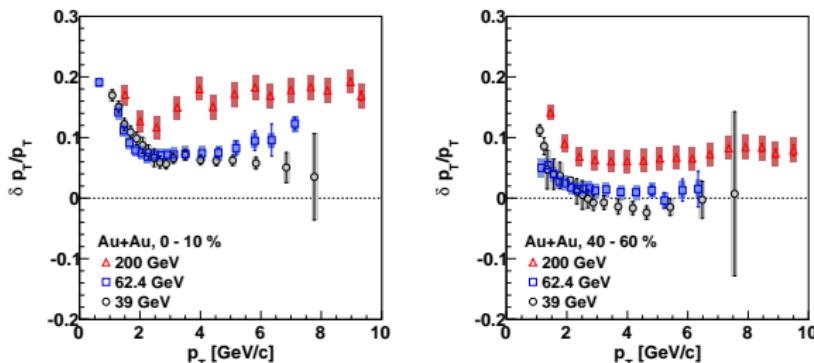
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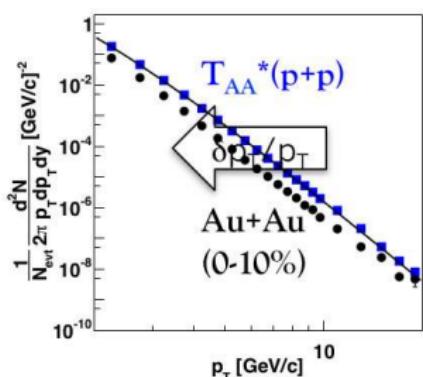


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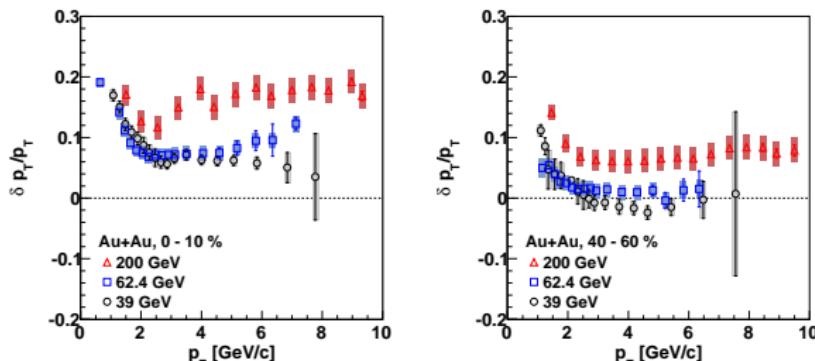
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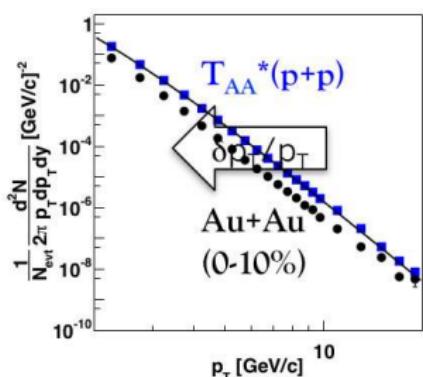


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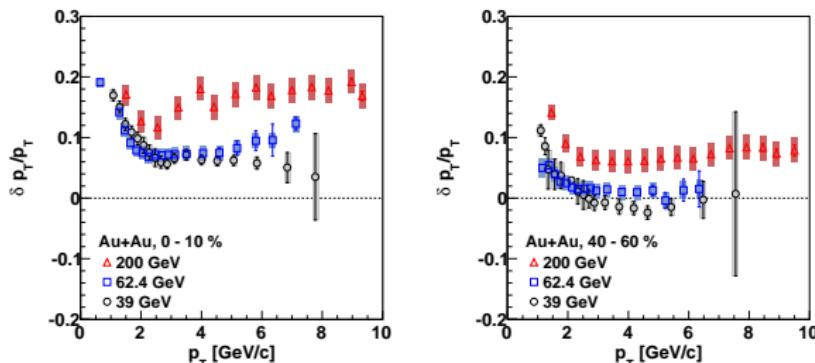
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x_T -scaling

x_T scaling in hard scattering

$$x_T = 2p_T/\sqrt{s}$$

$$E \frac{d^3\sigma}{dp^3} = \frac{1}{\sqrt{s}^{n(x_T, \sqrt{s})}} G(x_T)$$

LO QCD $n(x_T) = 4$

Obtaining the power between different $\sqrt{s_{NN}}$ values by linear approximation on the log scale

Effective power

$$n_{\text{eff}}(x_T) = \frac{\log \left(\frac{\text{Yield}(x_T, \sqrt{s_1})}{\text{Yield}(x_T, \sqrt{s_2})} \right)}{\log(\sqrt{s_2}/\sqrt{s_1})}$$

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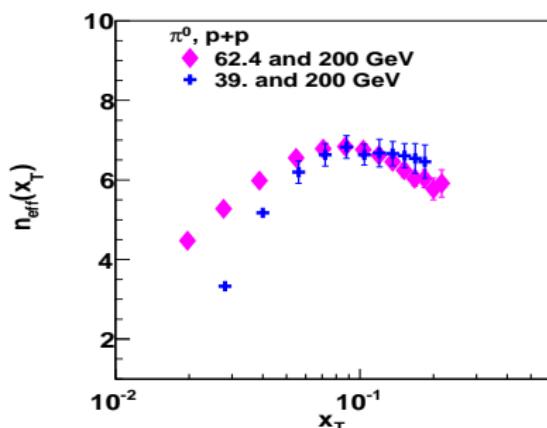
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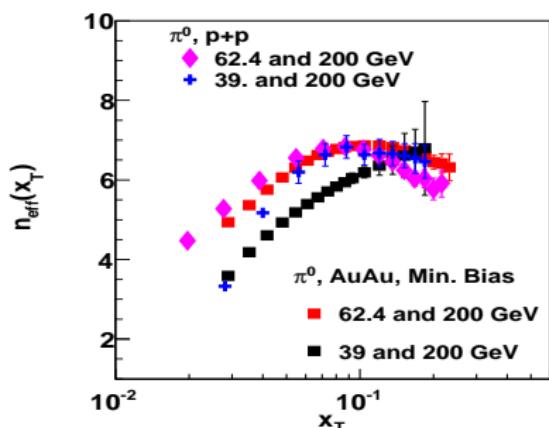
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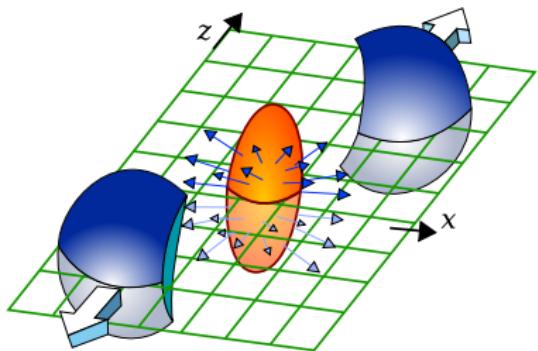
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Geometry



Flow: Initial spatial anisotropy converts to momentum anisotropy (v_2)

Red initial short pathlength

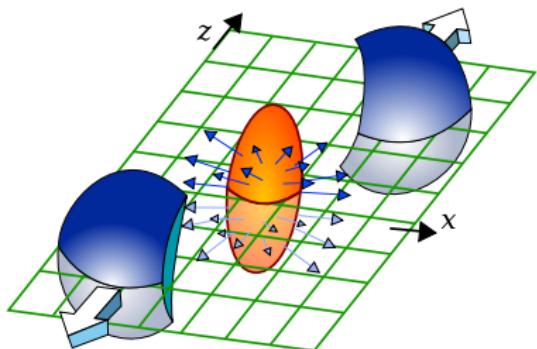
Cyan long pathlength

R_{AA} wrt. reaction plane $\sim R_{\text{AA}}$ wrt. path length

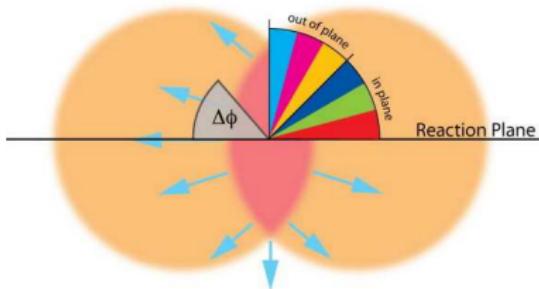
$$R_{\text{AA}}(p_{\text{T}}, \Delta\Phi) \approx R_{\text{AA}}(p_{\text{T}}) \times \frac{N(p_{\text{T}}, \Delta\Phi)}{\sum_i N(p_{\text{T}}, \Delta\Phi_i)}$$

$$N(p_{\text{T}}, \Delta\Phi_i) \approx N(1 + 2v_2 \cos(2\Delta\Phi_i))$$

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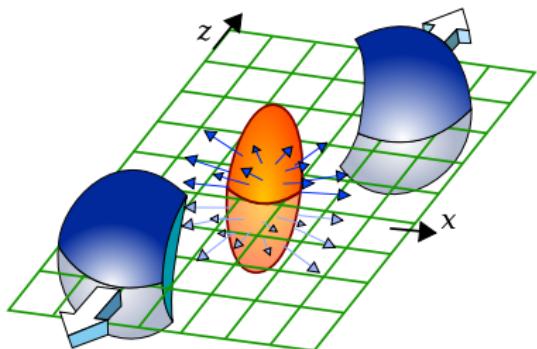
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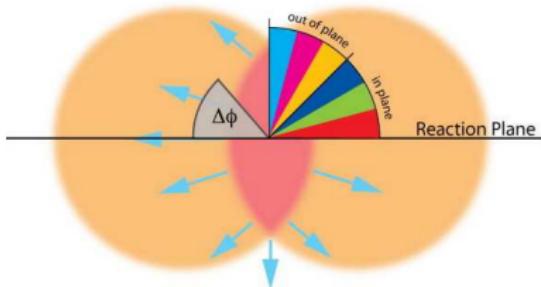
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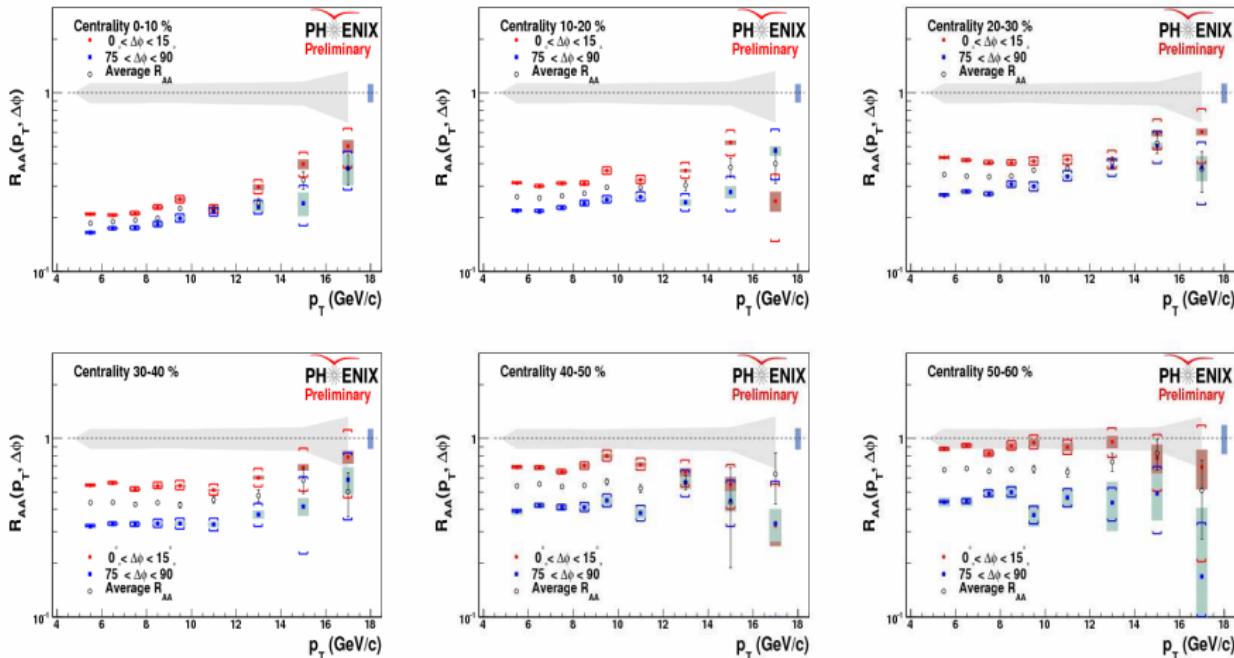
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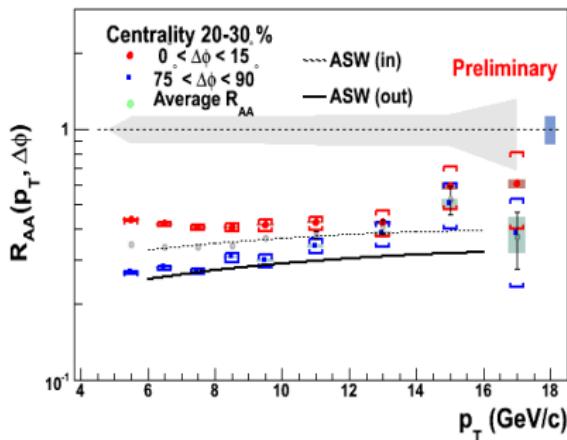
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2007 high luminosity, high p_T data



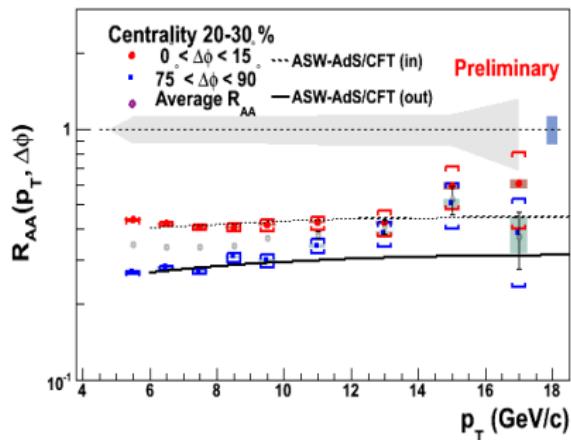
- Extends to $p_T = 19$ GeV/c in several centrality and $\Delta\Phi$ bins
- Centrality-dependent angular behavior seen

Model comparison in $R_{AA}(p_T, \Delta\phi)$



ASW in pQCD

Phys.Rev.C79,024901(2009)



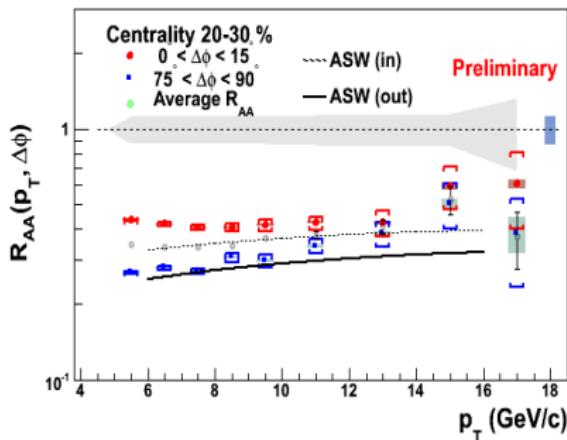
ASW in AdS/CFT

Phys.Lett.B685,270(2010)

$\Delta\phi$ -binned data able to differentiate b/w models

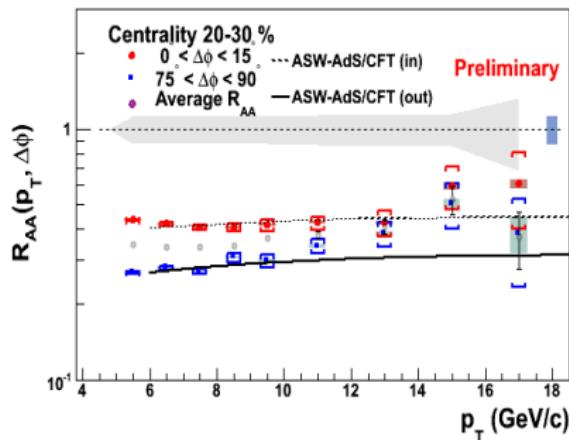
- Out-of-plane R_{AA} (large path length) reproduced by both
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Model comparison in $R_{AA}(p_T, \Delta\phi)$



ASW in pQCD

Phys.Rev.C79,024901(2009)



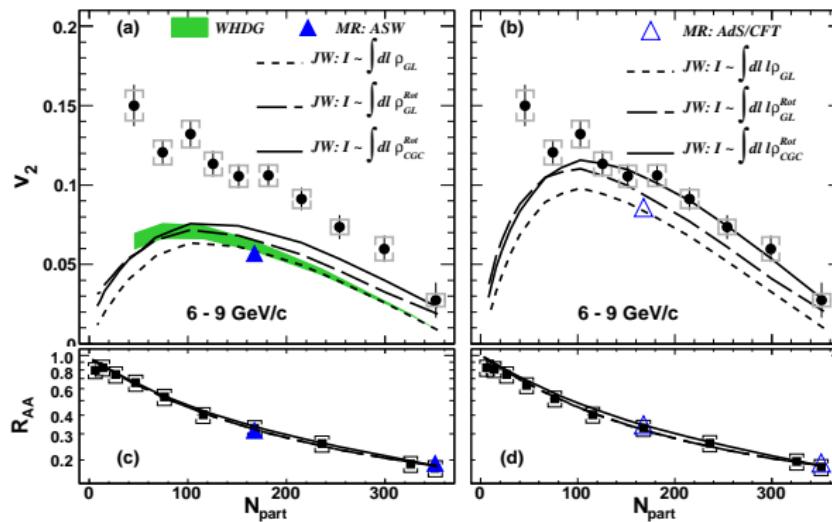
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Phys.Lett.B685,270(2010)

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Model comparison in v_2 and R_{AA} vs. N_{part}



3D hydro + pQCD

3D hydro + AdS/CFT

Energy loss models:

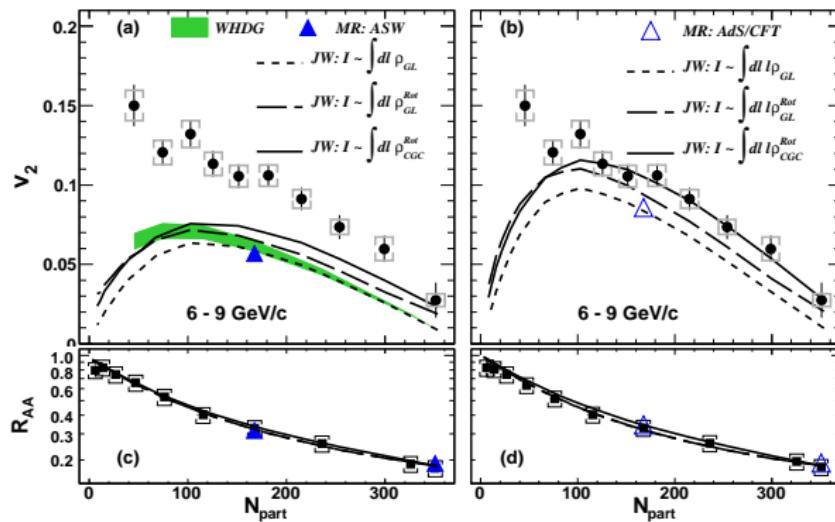
- **WHDG** (PQCD)
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- Only radiative processes

Initial geometry in JR:

- CGC (solid)
- Glauber (dotted)
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Flow also supports AdS/CFT-like path length dependence over pQCD

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Summary

- Evolution of π^0 suppression
 - In central collisions, production suppressed from 39 to 200 GeV
 - An enhancement is present at 39 GeV mid-peripheral collisions indicating a substantial Cronin effect
 - 62.4 GeV and 200 GeV R_{AA} are similar above $p_T < 5$ GeV
- Fractional energy loss
 - Largest at 200 GeV and in central collisions
- x_T -scaling
 - $n_{eff}(x_T)$ shows a very different trend when 39 vs. 200 GeV are compared
- Azimuth-dependent $R_{AA}(p_T, \Delta\Phi)$
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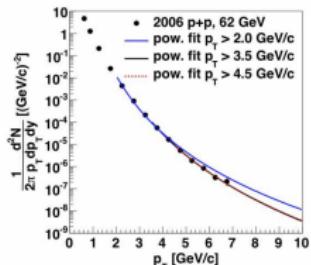
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BACKUP: p+p references for 39 GeV and 62.4 GeV

62 GeV



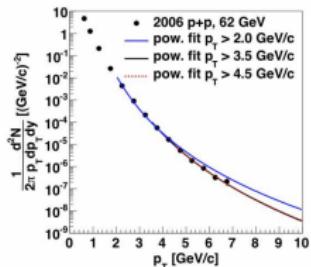
39 GeV

- p+p available up to $p_T < 7 \text{ GeV}$
- extrapolation: power-law function
- systematics on R_{AA}

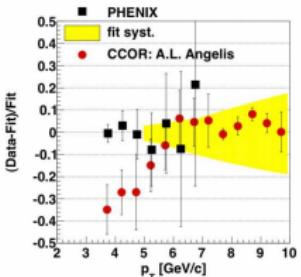
- p+p reference: Tevatron E0706 Phys.Rev.D68:052001,2003
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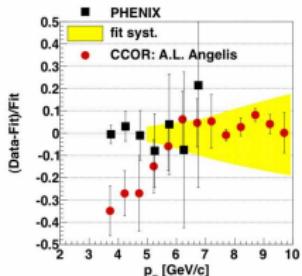
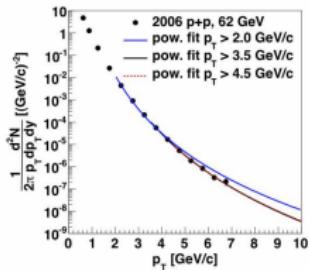


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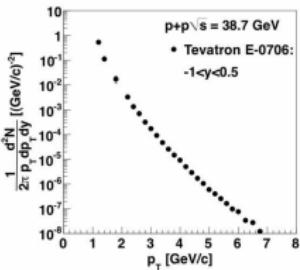
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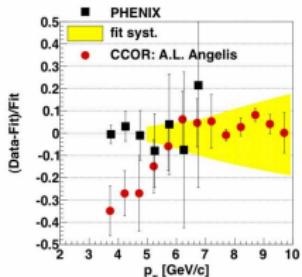
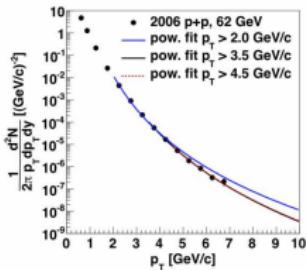


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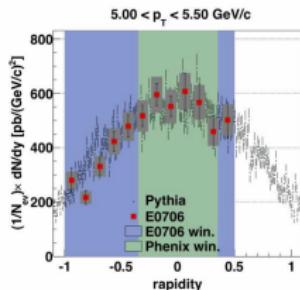
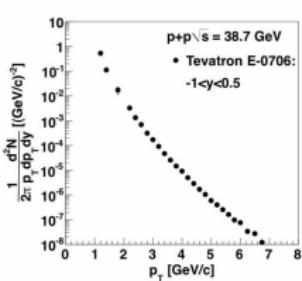
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